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Unlike the traditional approach where the performance can only be obtained from special calibration sessions that are both time-consuming and require manual setup, the new method taps into the daily spacecraft tracking data. This new approach significantly increases the amount of data available for analysis, roughly by two orders of magnitude, making it possible to conduct trend analysis with good confidence.

The software is built with automation in mind for end-to-end processing. From the inputs gathering to computation analysis and later data visualization of the results, all steps are done automatically, making the data production at near zero cost. This allows the limited engineering resource to focus on high-level assessment and to follow up with the exceptions/deviations.

To make it possible to process the continual stream of daily incoming data without much effort, and to understand the results quickly, the processing needs to be automated and the data summarized at a high level. Special attention needs to be given to data gathering, input validation, handling anomalous conditions, computation, and presenting the results in a visual form that makes it easy to spot items of exception/deviation so that further analysis can be directed and corrective actions followed.

This work was done by Timothy T. Pham, Richard J. Machuzak, Alina Bedrossian, Richard M. Kelly, and Jason C. Liao of Caltech for NASA's Jet Propulsion Laboratory.

For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47532.

③ Histogrammatic Method for Determining Relative Abundance of Input Gas Pulse

To satisfy the Major Constituents Analysis (MCA) requirements for the Vehicle Cabin Atmosphere Monitor (VCAM), this software analyzes the relative abundance ratios for N₂, O₂, Ar, and CO₂ as a function of time and constructs their best-estimate mean. A histogram is first built of all abundance ratios for each of the species vs time. The abundance peaks corresponding to the intended measurement and any obfuscating background are then separated via standard peak-finding techniques in histogram space. A voting scheme is then used to include/exclude this particular time sample in the final average based on its membership to the intended measurement or the background population. This results in a robust and reasonable estimate of the abundance of trace components such as CO₂ and Ar even in the presence of obfuscating backgrounds internal to the VCAM device.

VCAM can provide a means for monitoring the air within the enclosed environments, such as the ISS (International Space Station), Crew Exploration Vehicle (CEV), a Lunar Habitat, or another vehicle traveling to Mars. Its miniature pre-concentrator, gas chromatograph (GC), and mass spectrometer can provide unbiased detection of a large number of organic species as well as MCA analysis. VCAM's software can identify the concentration of trace chemicals and whether the chemicals are on a targeted list of hazardous compounds. This innovation's performance and reliability on orbit, along with the ground team's assessment of its raw data and analysis results, will validate its technology for future use and development.

This work was done by Lukas Mandrake, Benjamin J. Bornstein, Stojan Madzunkov, and John A. MacAskill of Caltech for NASA's Jet Propulsion Laboratory.

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the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47217.

④ Predictive Sea State Estimation for Automated Ride Control and Handling — PSSEARCH

PSSEARCH provides predictive sea state estimation, coupled with closed-loop feedback control for automated ride control. It enables a manned or unmanned watercraft to determine the 3D map and sea state conditions in its vicinity in real time. Adaptive path-planning/replanning software and a control surface management system will then use this information to choose the best settings and heading relative to the seas for the watercraft.

PSSEARCH looks ahead and anticipates potential impact of waves on the boat and is used in a tight control loop to adjust trim tabs, course, and throttle settings. The software uses sensory inputs including IMU (Inertial Measurement Unit), stereo, radar, etc. to determine the sea state and wave conditions (wave height, frequency, wave direction) in the vicinity of a rapidly moving boat. This information can then be used to plot a "safe" path through the oncoming waves.

The main issues in determining a safe path for sea surface navigation are: (1) deriving a 3D map of the surrounding environment, (2) extracting hazards and sea state surface state from the imaging sensors/map, and (3) planning a path and control surface settings that avoid the hazards, accomplish the mission navigation goals, and mitigate crew injuries from excessive heave, pitch, and roll accelerations while taking into account the dynamics of the sea surface state. The first part is solved using a wide baseline stereo system, where 3D structure is determined from two calibrated pairs of visual imagers.

Once the 3D map is derived, anything above the sea surface is classified as a potential hazard and a surface analysis gives a static snapshot of the waves. Dynamics of the wave features are obtained from a frequency analysis of motion vectors derived from the orientation of the waves during a sequence of inputs. Fusion of the dynamic wave patterns with the 3D maps and the IMU outputs is used for efficient safe path planning.

This work was done by Terrance L. Huntsberger, Andrew B. Howard, Hrand Aghazarian, and Arturo L. Rankin of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Refer to NPO-47533, volume and number of this NASA Tech Briefs issue, and the page number.

◉ **LEGION: Lightweight Expandable Group of Independently Operating Nodes**

LEGION is a lightweight C-language software library that enables distributed asynchronous data processing with a loosely coupled set of compute nodes. Loosely coupled means that a node can offer itself in service to a larger task at any time and can withdraw itself from service at any time, provided it is not actively engaged in an assignment. The main program, i.e., the one attempting to solve the larger task, does not need to know up front which nodes will be available, how many nodes will be available, or at what times the nodes will be available, which is normally the case in a "volunteer computing" framework. The LEGION software accomplishes its goals by providing message-based, inter-process communication similar to MPI (message passing interface), but without the tight coupling requirements. The software is lightweight and easy to install as it is written in standard C with no exotic library dependencies.

LEGION has been demonstrated in a challenging planetary science application in which a machine learning system is used in closed-loop fashion to efficiently explore the input parameter space of a complex numerical simulation. The machine learning system decides which jobs to run through the simulator; then, through LEGION calls, the system farms those jobs out to a collection of compute nodes, retrieves the job results as they become available, and updates a predictive model of how the simulator maps inputs to outputs. The machine learning system decides which new set of jobs would be most informa-

tive to run given the results so far; this basic loop is repeated until sufficient insight into the physical system modeled by the simulator is obtained.

This work was done by Michael C. Burl of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47910.

◉ **Real-Time Projection to Verify Plan Success During Execution**

The Mission Data System provides a framework for modeling complex systems in terms of system behaviors and goals that express intent. Complex activity plans can be represented as goal networks that express the coordination of goals on different state variables of the system. Real-time projection extends the ability of this system to verify plan achievability (all goals can be satisfied over the entire plan) into the execution domain so that the system is able to continuously re-verify a plan as it is executed, and as the states of the system change in response to goals and the environment.

Previous versions were able to detect and respond to goal violations when they actually occur during execution. This new capability enables the prediction of future goal failures; specifically, goals that were previously found to be achievable but are no longer achievable due to unanticipated faults or environmental conditions. Early detection of such situations enables operators or an autonomous fault response capability to deal with the problem at a point that maximizes the available options.

For example, this system has been applied to the problem of managing battery energy on a lunar rover as it is used to explore the Moon. Astronauts drive the rover to waypoints and conduct science observations according to a plan that is scheduled and verified to be achievable with the energy resources available. As the astronauts execute this plan, the system uses this new capability to continuously re-verify the plan as energy is consumed to ensure that the battery will never be depleted below safe levels across the entire plan.

In particular, this enables an execution system to predict problems such as resource exhaustion before they occur. The models are expressed and executed in a way that can be optimized for real-

time use in an embedded system.

This work was done by David A. Wagner, Daniel L. Dvorak, Robert D. Rasmussen, Russell L. Knight, John R. Morris, Matthew B. Bennett, and Michel D. Ingham of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

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